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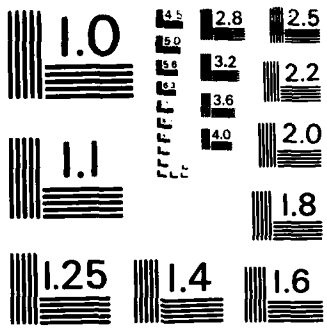

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NRL Memorandum Report 5286

A Method to Compute the Contact Force of a Body Impacting a Ring-Stiffened Cylindrical Shell Using a Lumped Parameter Finite-Difference Model

R. S. SCHECHTER

Structural Integrity Branch
Marine Technology Division

March 12, 1984

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A method to compute the contact force of a body impacting a ring-stiffened cylindrical shell using a lumped parameter finite-difference computer program is presented. The method is applied to a simulator torpedo. The derived force predicts velocity responses and shock spectra which agrees well with measurements.

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11. TITLE

A METHOD TO COMPUTE THE CONTACT FORCE OF A BODY IMPACTING A RING-STIFFENED CYLINDRICAL SHELL USING A LUMPED PARAMETER FINITE-DIFFERENCE MODEL

CONTENTS

A METHOD TO COMPUTE THE CONTACT FORCE OF A BODY IMPACTING A RING-STIFFENED CYLINDRICAL SHELL USING A LUMPED PARAMETER FINITE-DIFFERENCE MODEL

INTRODUCTION

The Naval Research Laboratory has in the past been involved in defining shock design inputs for equipment aboard submarines. The Navy is currently involved in sea-exercises in which inert torpedoes with high velocities are being used. With the possibility of a torpedo impacting a submarine and damaging vital equipment, resulting in loss of life and the submarine, a reliable method to estimate the impact force is needed. This report presents a method to compute the contact force of a body such as an inert torpedo impacting a ring-stiffened cylindrical shell using a lumped parameter finite-difference computer program.

The method is very simple in concept. The measured velocity of the struck region is impressed on the lumped mass around the impact point in the computer model. The computer program for each time step calculates the velocity of the struck mass assuming no impact force. All the internal forces on the mass are calculated by the program. The calculated velocity is in error. The force necessary to move the mass at the correct velocity (impressed velocity) is computed at each time step. This additional force is the impact force.

The method has several important advantages. The data measured at the impact point are used to drive the mathematical model. The response of the model at each time step gives the impact force at the previous time step, and for shock type loadings of 10-30 ms the model has little time to degrade in accuracy. In addition, because of the short duration of the calculation, damping plays little part.

A previous report "A Method to Compute the Force Signature of a Body Impacting on a Linear Elastic Structure Using Fourier Analysis" [1] discusses a frequency domain technique for deriving the impact force. This method suffers from several major drawbacks. In order to obtain convergence of the Fourier integrals of the impulse response and response to force, functions out to long times must be used. The long times required introduce errors in the derived force due to errors in the measured gage response and errors in the computer impulse response, especially at late times. In order to use the computed impulse response damping must be applied to the function. Obtaining the correct damping as function of frequency is another difficulty, and introduces errors in the derived force.

Manuscript approved December 29, 1983.

EXPERIMENT - TORPEDO IMPACT

In 1982, a series of rocket assisted air drops of various torpedoes was conducted by NSRDC-UERD (Naval Ship Research and Development Center - Underwater Explosion Research Detachment) at Portsmouth, Virginia. The torpedoes were dropped against a large ring-stiffened cylindrical shell made of HY-130 steel, also known as the AB-1. Data were measured on the AB-1 by velocity meters and accelerometers during the impact. The locations of these velocity meters and accelerometers in the vicinity of the impacted frame are shown in Figure 1.

One of the impactors dropped was a simulator torpedo (an impactor designed to simulate the force of an actual torpedo). Data was sent to NRL on digital tape. The method as described in this report is applied to this data set as a test case. The data from the impact region are used to generate the force. This impact force is then used with the damped computed impulse response to generate predicted responses for various gage locations. From the predicted responses predicted shock spectra may be obtained and compared with measured shock spectra. Predicting shock spectra is of prime importance in design and analyses of internal equipments by current methods.

METHOD USING VGSM TO FIND IMPACT FORCE

VGSM (the Variable Geometry Submarine Model) [2] employs a lumped parameter finite difference approach to model the response of ring-stiffened cylindrical shells. The program solves the partial differential equations of Timoshenko beam theory. A model generator program is supplied to generate the cylindrical shell with stiffeners. The user must write a main program which contains the additional equipment equations and calls the dynamic subroutine which updates (integrates in time) the response of the masses modeling the shell. The main program integrates the equipment equations. The model time histories to be printed out, or saved on disk/tape, must be defined in the user-supplied main program.

The sequence of steps which is used to model the AB-1 and compute the impact force is as follows. First the model generator program is used to build a 7-frame model of the AB-1 cylinder. Then a main program is written to model the equipment. The simulated equipment mounted between frames (see figure 1) is modeled by two equations of motion. The equipment equations in matrix form are:

$$[M][\ddot{X}] + [K][X] = [K][T][Y] \qquad (1)$$

where M is the diagonal lumped mass matrix, K is the symmetrical stiffness matrix of the equipment, X is the column vector of equipment mass displacements, Y is the column vector of VGSM mass displacements at the equipment supports and T is a matrix transforming VGSM displacements at supports to equipment displacements at lumped masses. The reaction forces at the equipment supports can be expressed as:

$$[FR] = [T][\ddot{X}] \begin{bmatrix} M_1 \\ M_2 \end{bmatrix} \qquad (2)$$

The measured velocity of the shell at the impact point is low pass filtered to remove noise and obtain a smooth signal. The VGSM mass corresponding to the impact point is moved with the filtered measured velocity VM_i at time t_i. The AB-1 model and equipment is then allowed to move for one time step and VGSM returns for the struck mass a velocity of VY_{i+1} at time t_{i+1}, which differs from VM_{i+1}, the measured velocity at t_{i+1}. The impact force TF needed to make the VGSM mass velocity equal to the measured velocity VM_{i+1} can be computed from:

$$TF_i = FR_i + \frac{M}{\Delta t}\left(VY_{i+1} - VM_{i+1}\right) \qquad (3)$$

This equation may be turned around to read:

$$VM_{i+1} = VY_{i+1} + \left(\frac{FRi - TFi}{M}\right)\Delta t \qquad (4)$$

This equation says that the measured velocity at t_{i+1} is equal to the VGSM velocity at t_{i+1} corrected by the velocity change due to the upward equipment reaction force $\frac{FRi}{M}\Delta t$ at ti and the downward impact force $\frac{-TFi}{M}\Delta t$ at t_i. The VGSM mass velocity is then set to the measured velocity at t_{i+1}, the model is allowed to move for one time step, and equation 3 is again used to find TF_{i+1}. The sequence for finding TF is programmed into the user supplied main program.

RESULTS OF METHOD

The above method is applied to compute the contact force of a simulator torpedo dropped on the AB-1. Figure 2 shows the unfiltered velocity as measured by V11, on the end of the flange under the impact on frame 9. Figure 3 shows the velocity record from V11 low-pass filtered below 500Hz. The filtered velocity V11 drives the VGSM struck mass. Figure 4 shows the impact force calculated at each time step. The negative values represent modeling errors since there is no mechanism for the impactor to pull up on the AB-1, creating negative or tensile forces. Figure 5 shows the impact force with negative values removed and terminated at a time corresponding to no additional impulse being delivered. Figure 6 shows the momentum or impulse delivered to the AB-1. After the initial momentum of 4663 lb-s is expended a substantial additional impulse is calculated due to a large bounce of the simulator also observed during the drop. Some impactors do not bounce and the calculated impulse expended then equals MV_o, the initial momentum of the impactor. Figure 7 shows the velocity of the simulator center of gravity. The simulator slows down and then reverses direction as it bounces. Figure 8 shows the displacement or crushing of the impactor. The simulator crushes about 5 inches during impact, close to the measured 6 inches. Figure 9 shows the energy expended by the simulator during impact. The initial kinetic energy ($1/2\ MV_o^2$) of 159,017 lb-ft of the simulator is totally expended.

COMPARISON OF PREDICTED AND MEASURED RESPONSES

One method of comparison of predicted versus measured is to move the VGSM struck mass with the measured velocity and compare the velocity computed to the measured velocity at the neighboring frames and on the simulated equipment. This amounts to comparing measured and computed velocities during the time that the force is computed. Figures 10, 11 and 12 show good agreement between predicted and measured time histories on frames in the vicinity of the impact frame. Figures 13 and 14 also show good agreement between predicted and measured velocity time histories on the simulated equipment. It should be noted that the measured data has an arbitrary zero time, however by shifting the measure curve right or left a better match can be obtained.

Another method of comparison is to convolve the truncated force (no negative values and terminated after impulse is expended) and a VGSM computed impulse response to obtain a predicted response. The computed impulse response should be damped. The following method is employed. Shock spectra of experimental records for various lengths of time are produced. The growth of peaks at different frequencies in the shock spectrum is used to estimate an equivalent viscous damping factor in five frequency bands from 0 to 500 Hz. The estimate is based on using the growth of the analytical solution of an undamped shock spectrum oscillator to damped base motion. The ratio of the amplitudes at two different times gives the damping in the base. Damping factors obtained by this technique ranged from 1% to 3% of critical.

Impulsive responses for the instrumented frames and locations on the simulated equipment are found using VGSM. Each impulse response is broken into the same five frequency bands as the data by using band-pass filters, and the time histories for each band are modified by the exponential damping factors. The damped time histories for each of the five bands are summed to form a damped impulse response. The response of a linear elastic system such as the AB-1 may be computed from the convolution integral:

$$Ri(t) = \int_o^t F(\tau)hi(t-\tau)d\tau \qquad (5)$$

This equation is the convolution of the impact force and the damped impulse response at location i. The $R_i(t)$ are computed for locations on the impact frame, neighboring frames, and on the simulated equipment using a Fourier transform computer code.

Then undamped shock spectra are computed using these predicted responses as the base motion of the shock spectrum oscillator. These predicted shock spectra are plotted on a linear scale along with measured shock spectra from velocity meters and accelerometers mounted in the vicinity of locations corresponding to VGSM predictions. Figures 15-18 show good agreement between measured and predicted 50 MS shock spectra on the impacted frame and those that are adjacent, and Figures 19-20 show good agreement on the simulated equipment.

CONCLUSIONS

A valid method for obtaining the contact force of a body such as a torpedo impacting a ring-stiffened cylinder has been described. The method is tested on data from a simulator torpedo. The calculated force is consistent with measured data in many respects; momentum, energy and crush. The derived force in turn predicts velocity responses and shock spectra which agree well with measurements. The same method has been used successfully to obtain the impact force of real torpedoes such as the Mk48.

ACKNOWLEDGMENTS

The author would like to express his gratitude to George J. O'Hara for his help and assistance in the formulation of many ideas in this report.

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1. O'Hara, G.J. and Schechter, R.S., "A Method to Compute the Force Signature of a Body Impacting on a Linear Elastic Structure Using Fourier Analysis", NRL Memorandum Report 4875, September 1982. AD-A119 747

2. McNaight, B.C., "The Variable Geometry Submarine Model (VGSM), Version III, User's Manual", M & T Report No. A790902, The M & T Company, Sept. 1979.

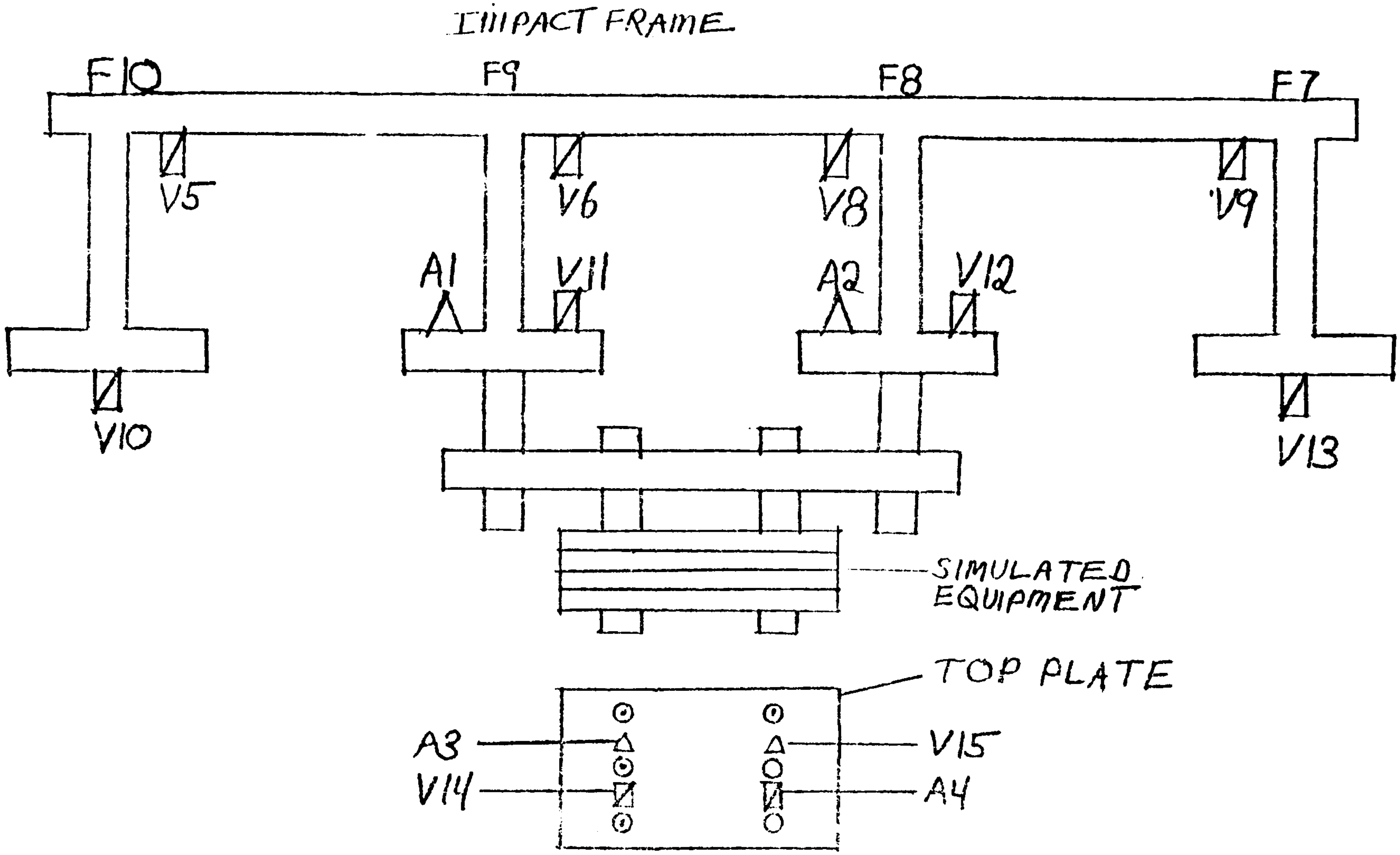

FIGURE 1 - SKETCH SHOWING LOCATION OF FRAMES, VELOCITY METERS AND ACCELEROMETERS ON AB-1 IN VICINITY OF SIMULATED EQUIPMENT.

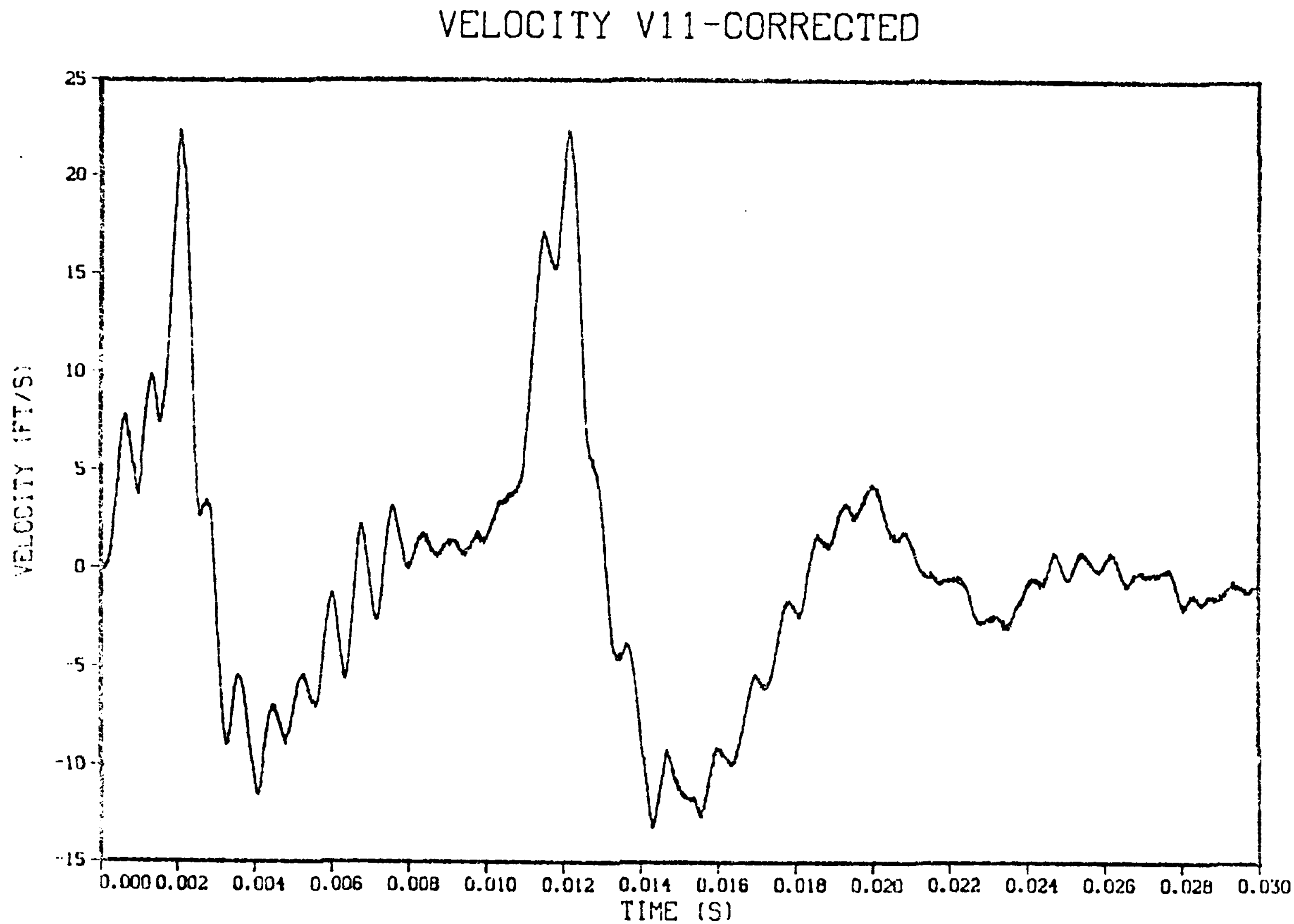

FIGURE 2 -- UNFILTERED VELOCITY OF IMPACT REGION MEASURED BY VELOCITY METER V11.

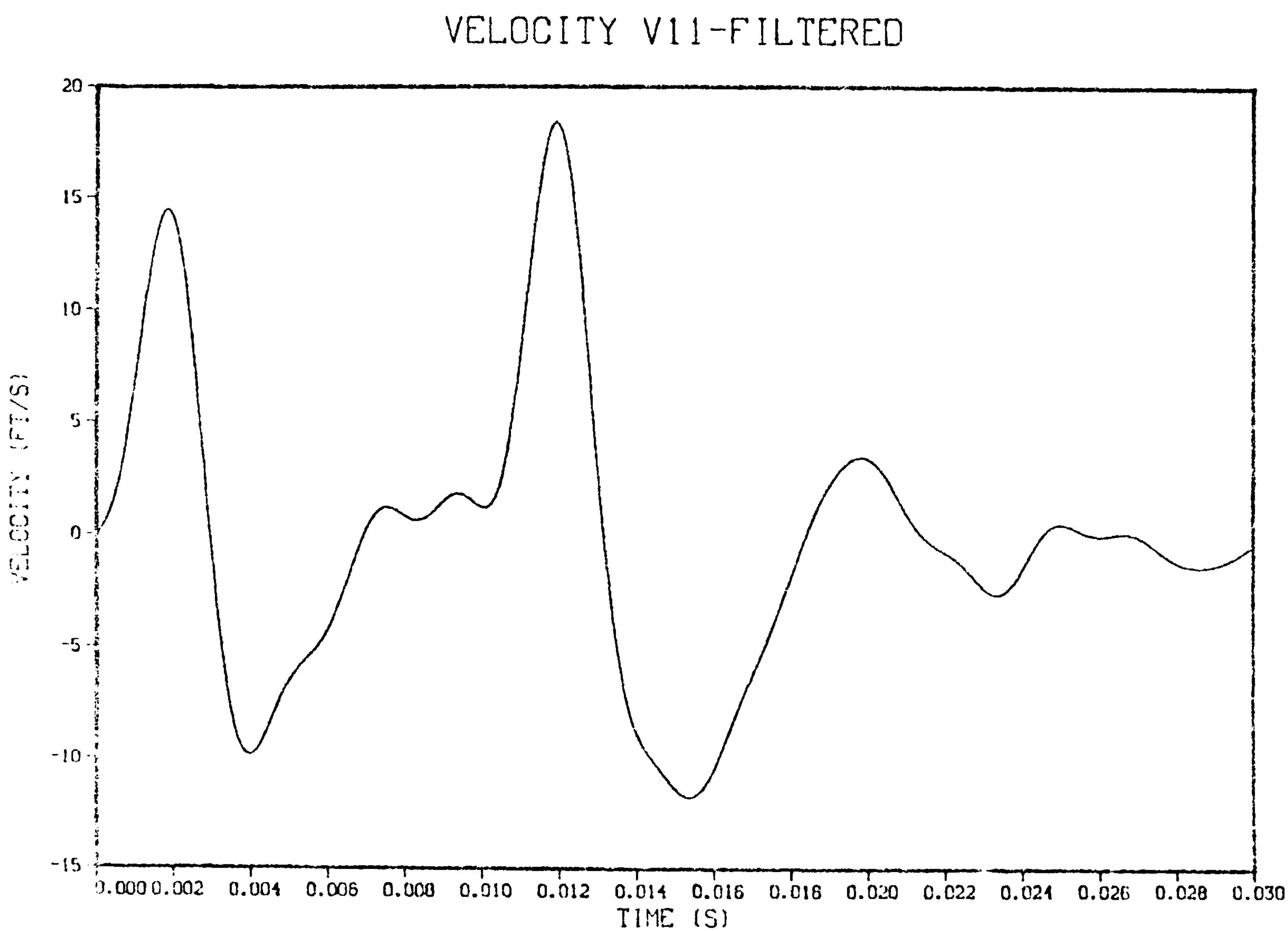

FIGURE 3 - LOW PASS FILTERED VELOCITY OF IMPACT REGION MEASURED BY VELOCITY METER V11.

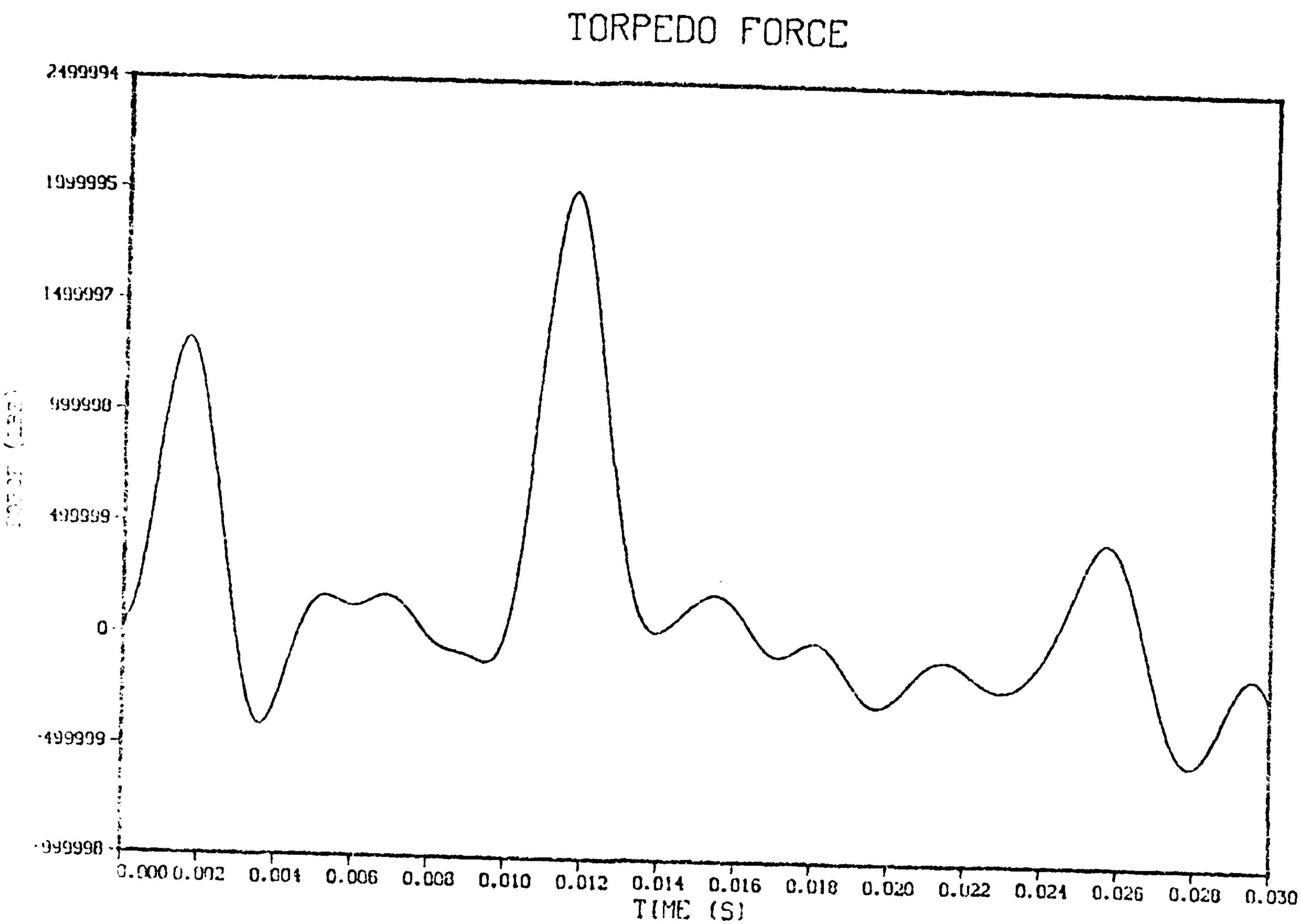

FIGURE 4 - FORCE OF SIMULATOR TORPEDO COMPUTED BY VGSM.

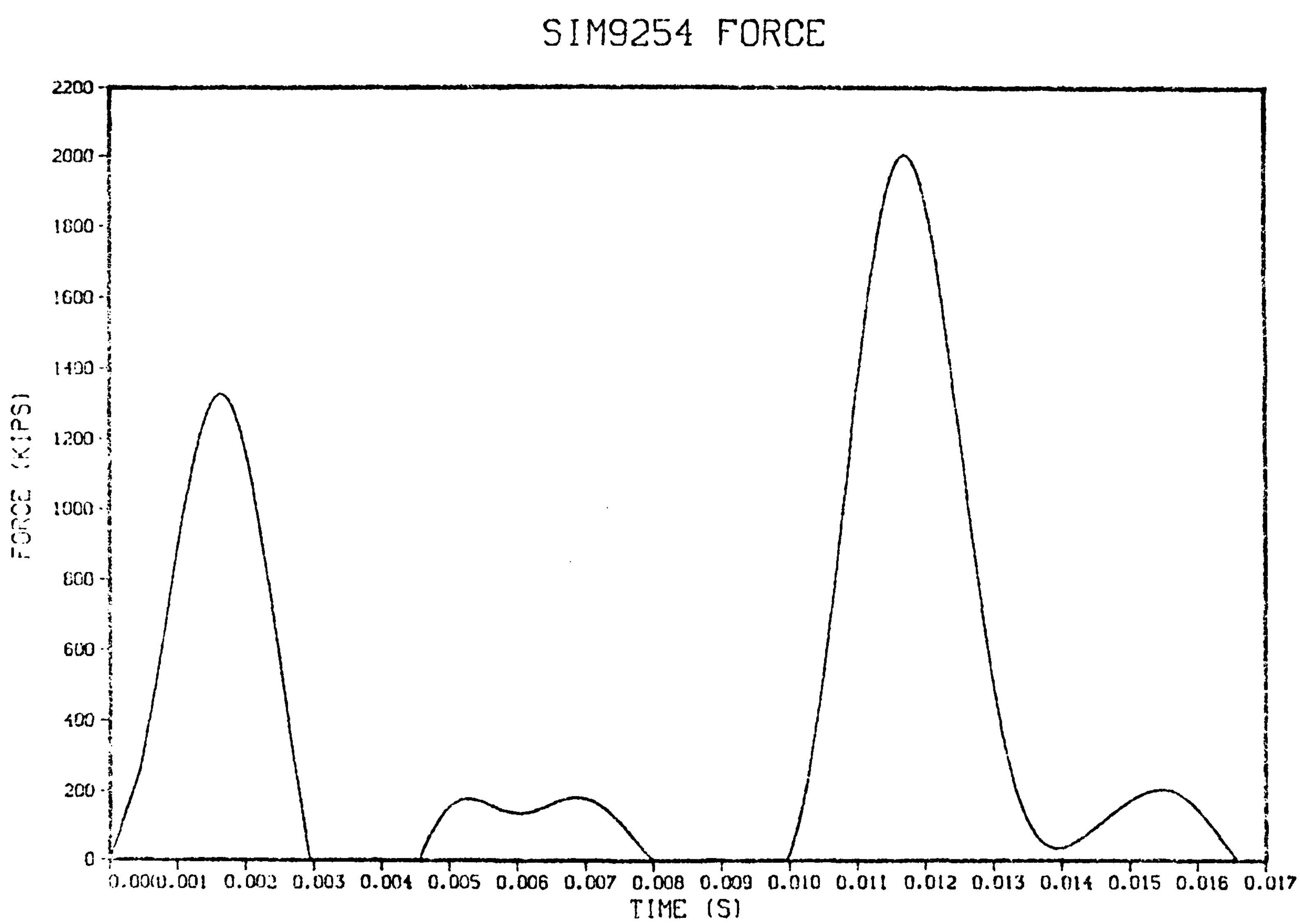

FIGURE 5 - IMPACT FORCE OF SIMULATOR TORPEDO WITH NEGATIVE VALUES REMOVED AND TERMINATED IN TIME.

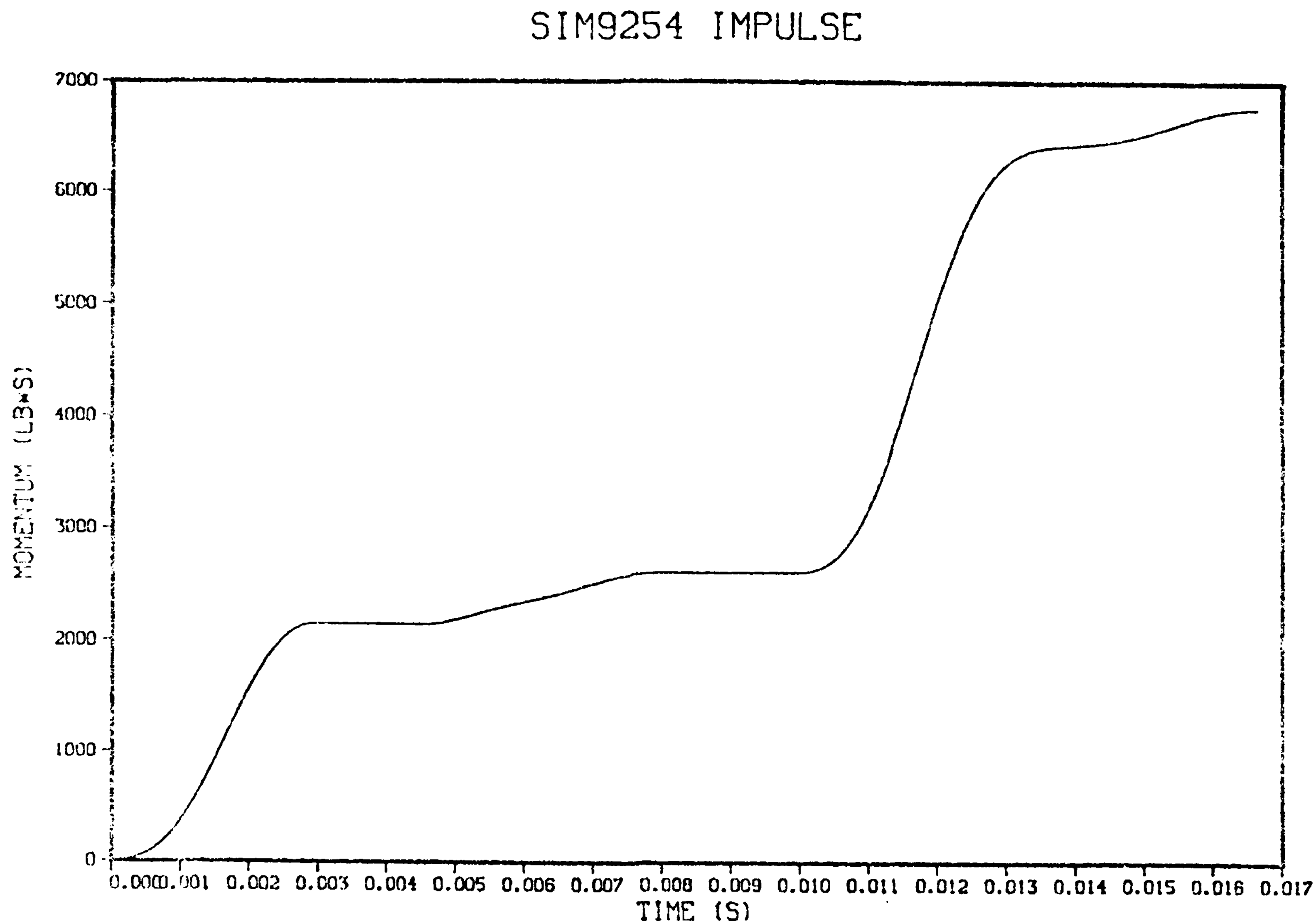

FIGURE 6 - IMPULSE OR EXPENDED MOMENTUM OF SIMULATOR.

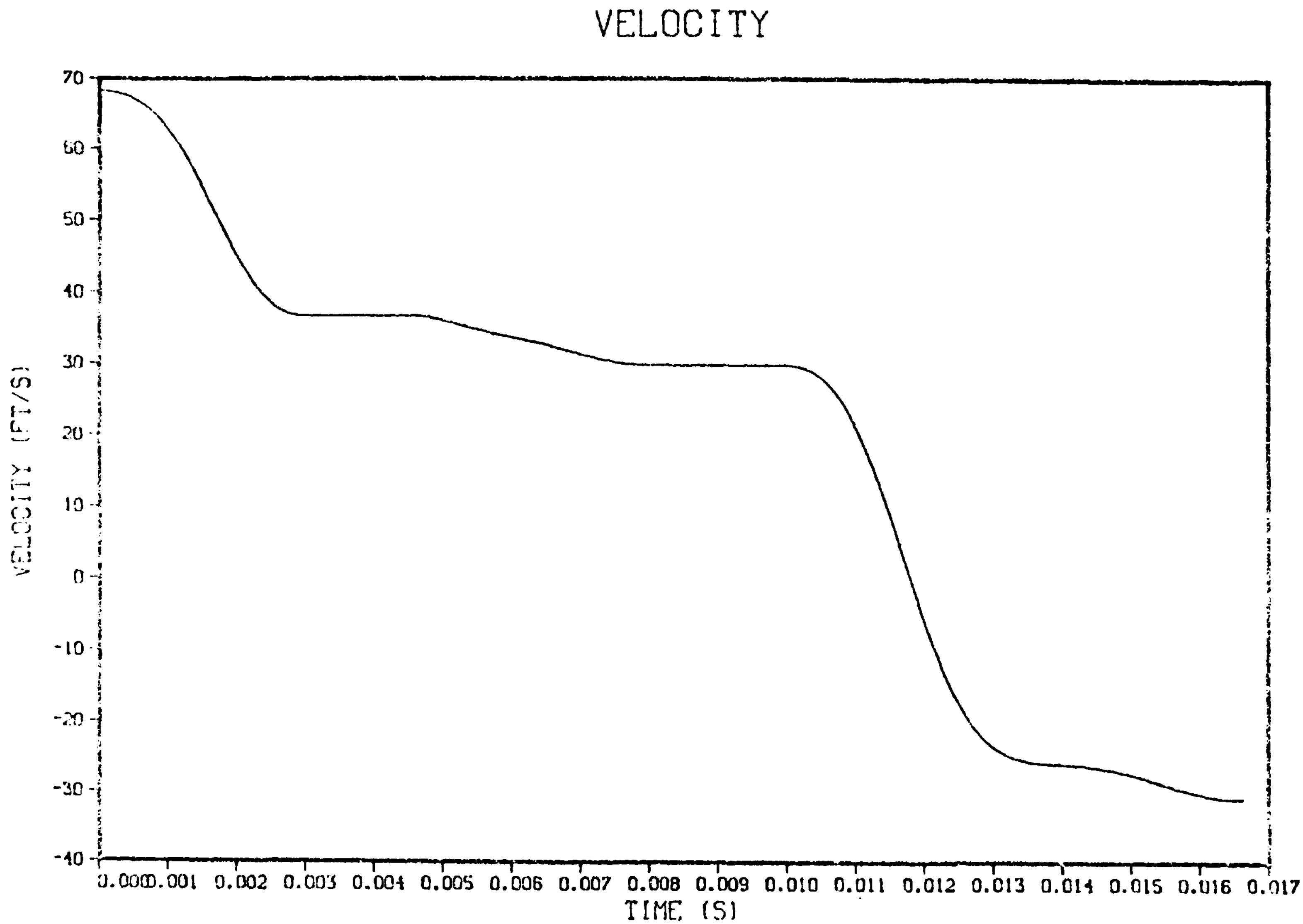

FIGURE 7 - VELOCITY OF C.G. OF SIMULATOR.

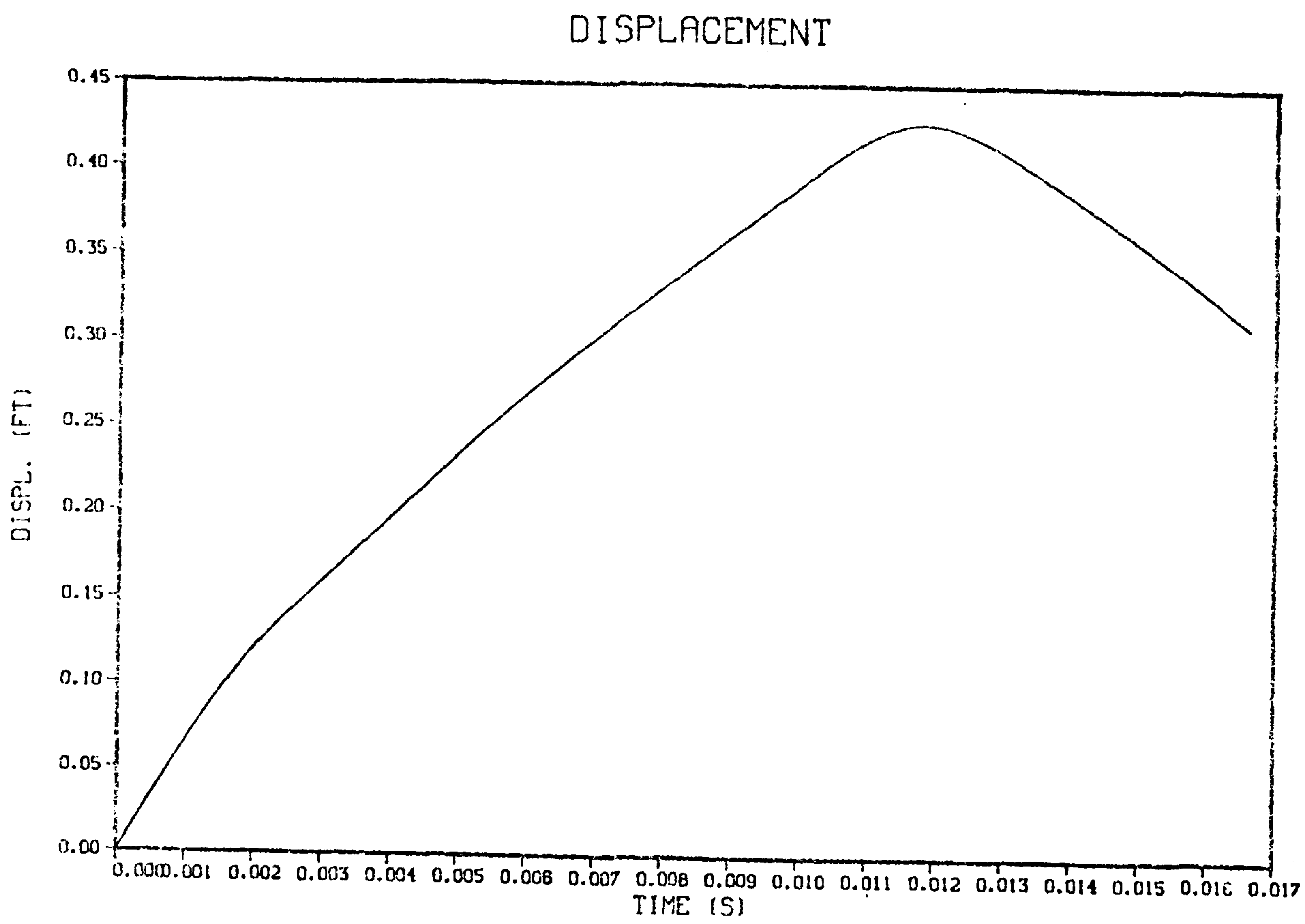

FIGURE 8 - DISPLACEMENT OF C.G. OR CRUSHING OF SIMULATOR.

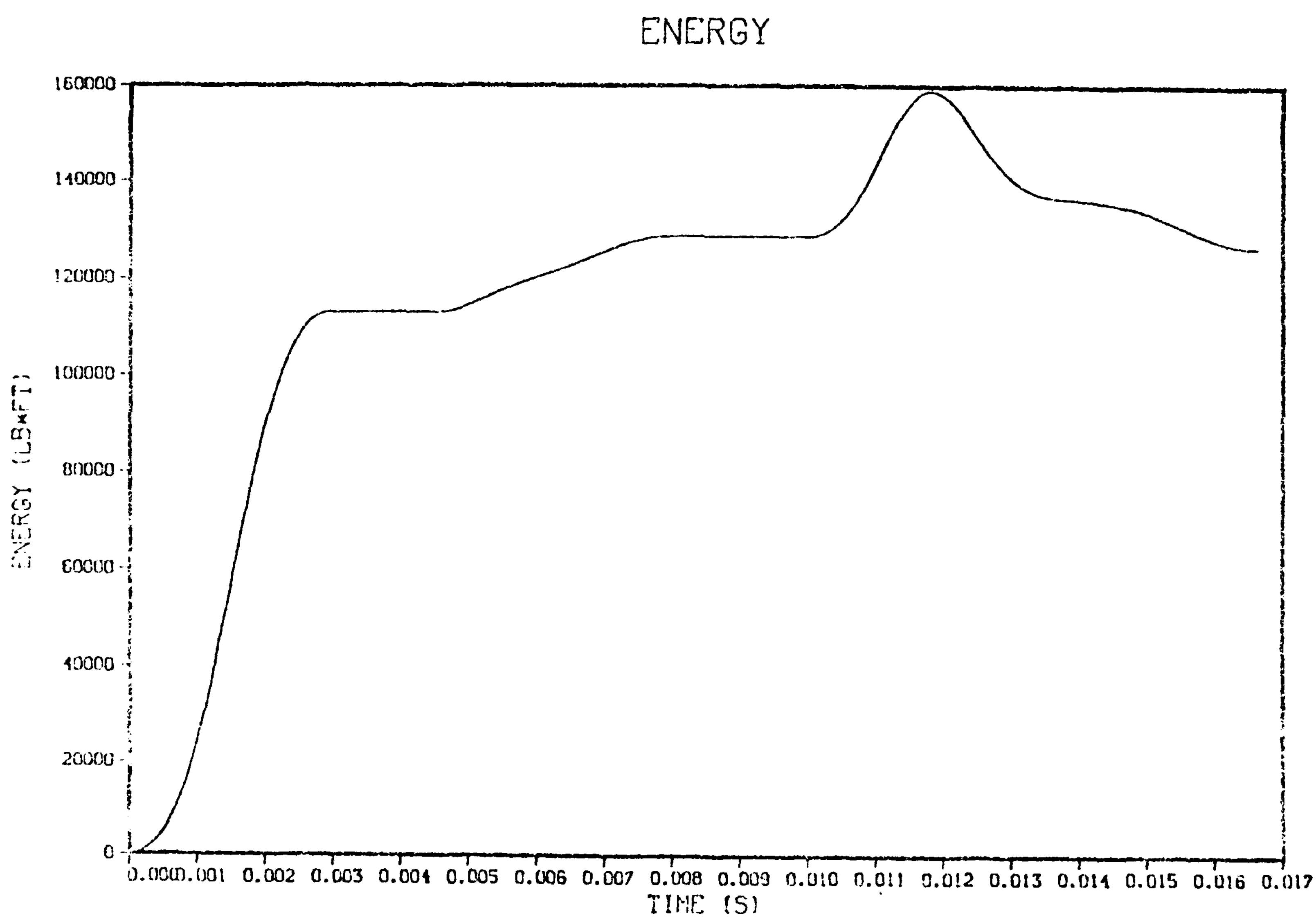

FIGURE 9 - ENERGY EXPENDED BY SIMULATOR.

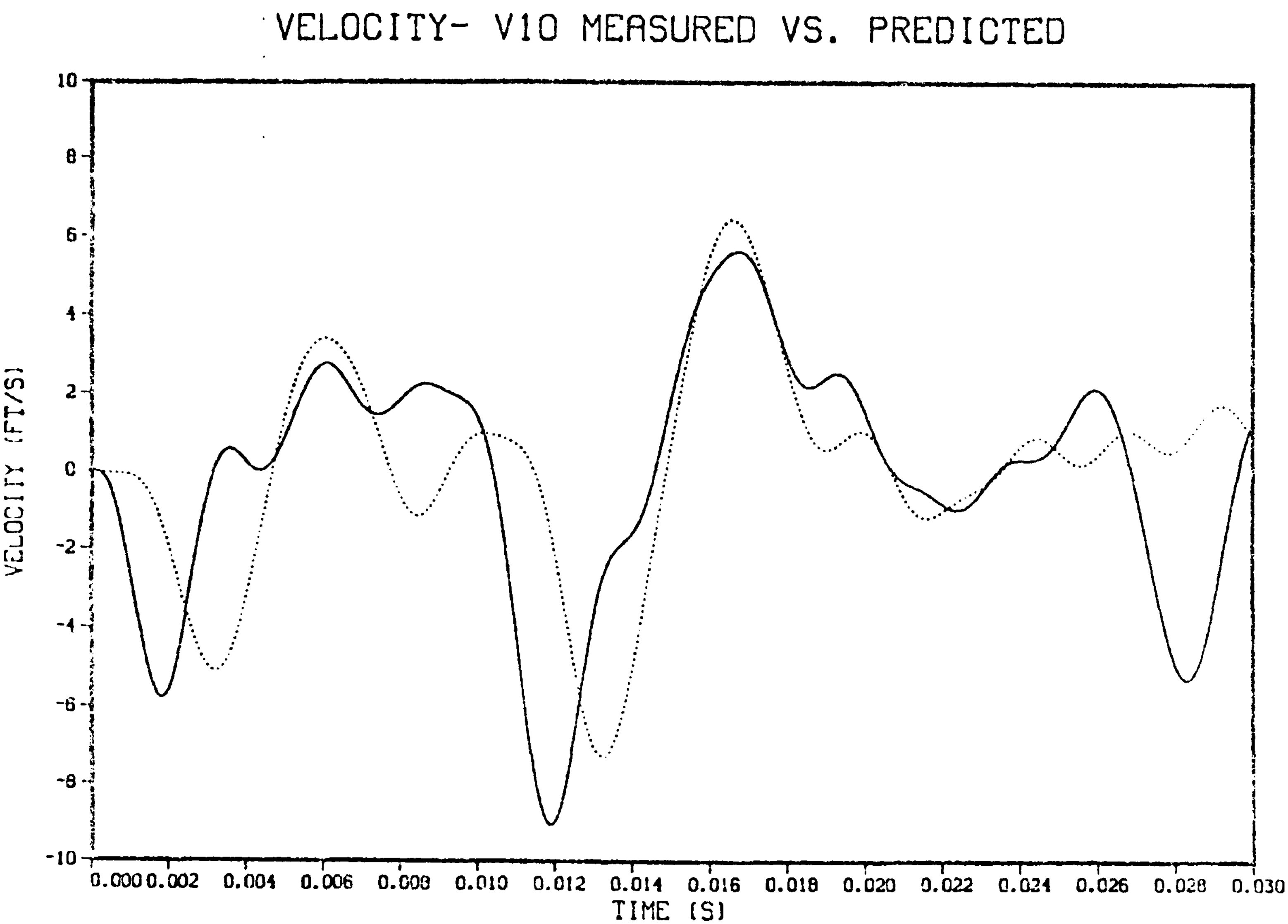

FIGURE 10 - COMPARISON OF VELOCITY MEASURED ON FRAME 10 BY VELOCITY METER V10 (...) VERSUS PREDICTED (——).

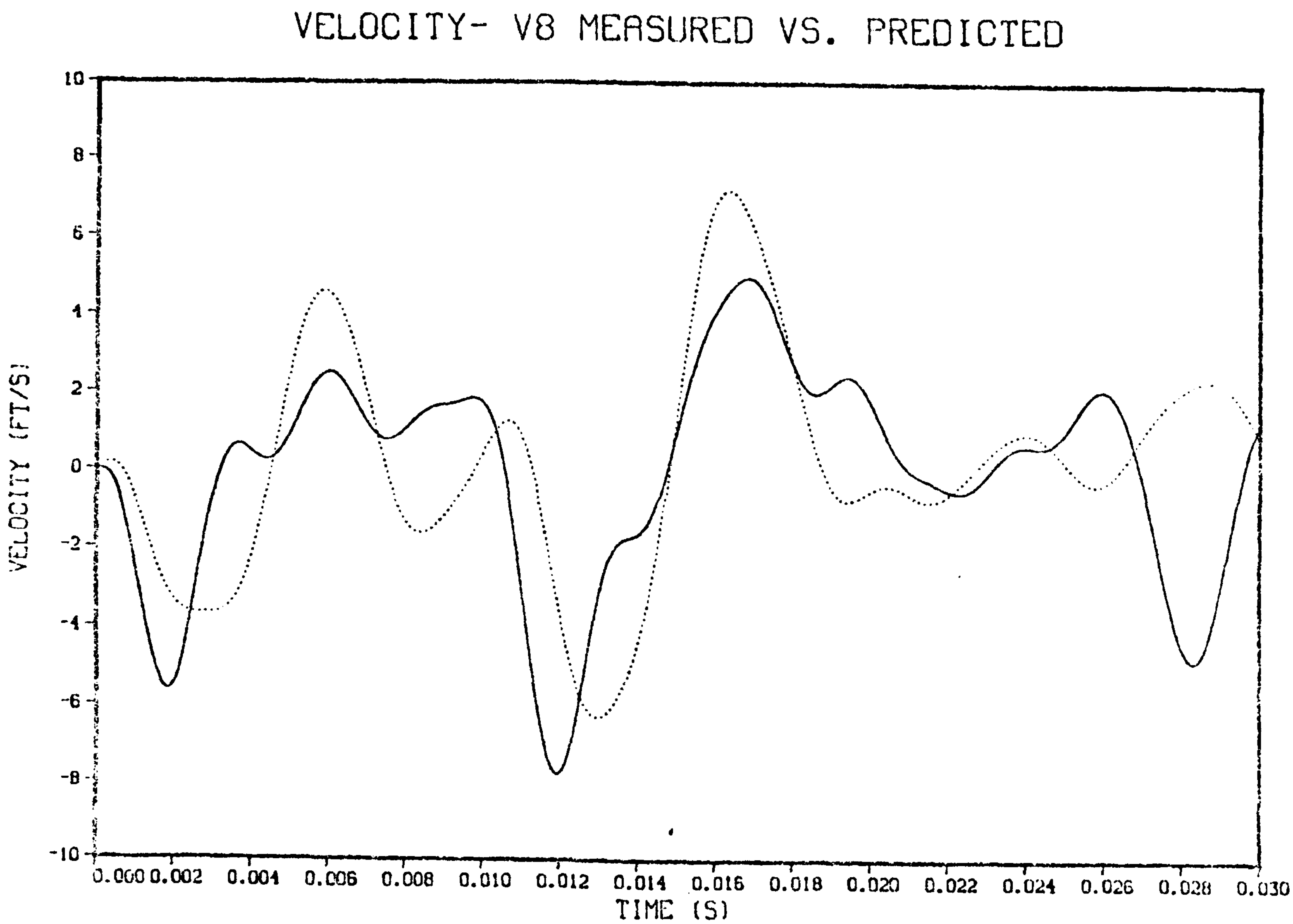

FIGURE 11 - COMPARISON OF VELOCITY MEASURED ON FRAME 8 BY VELOCITY METER V8 (...) VERSUS PREDICTED (——).

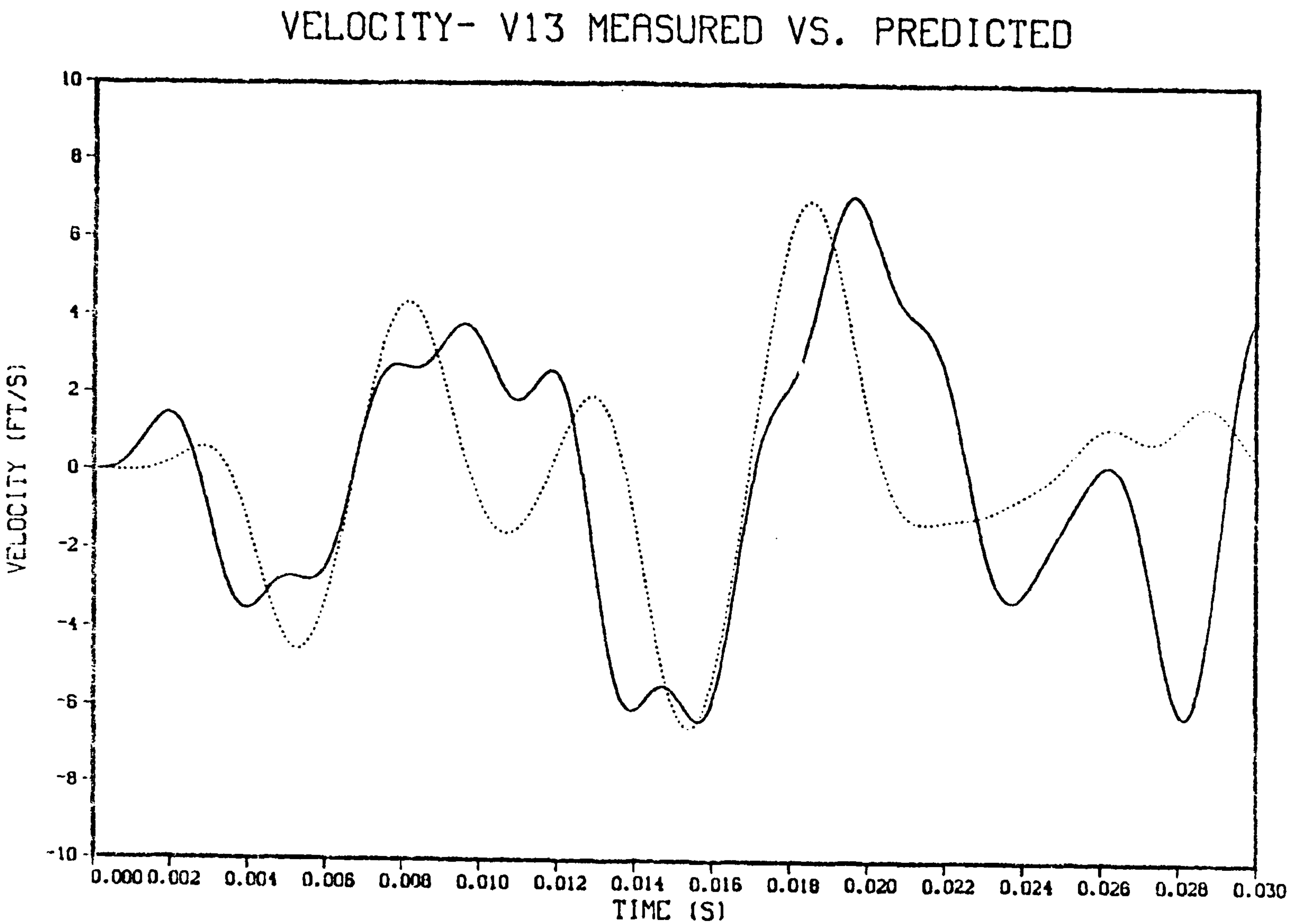

FIGURE 12 - COMPARISON OF VELOCITY MEASURED ON FRAME 7 BY VELOCITY METER V13 (...) VERSUS PREDICTED (——).

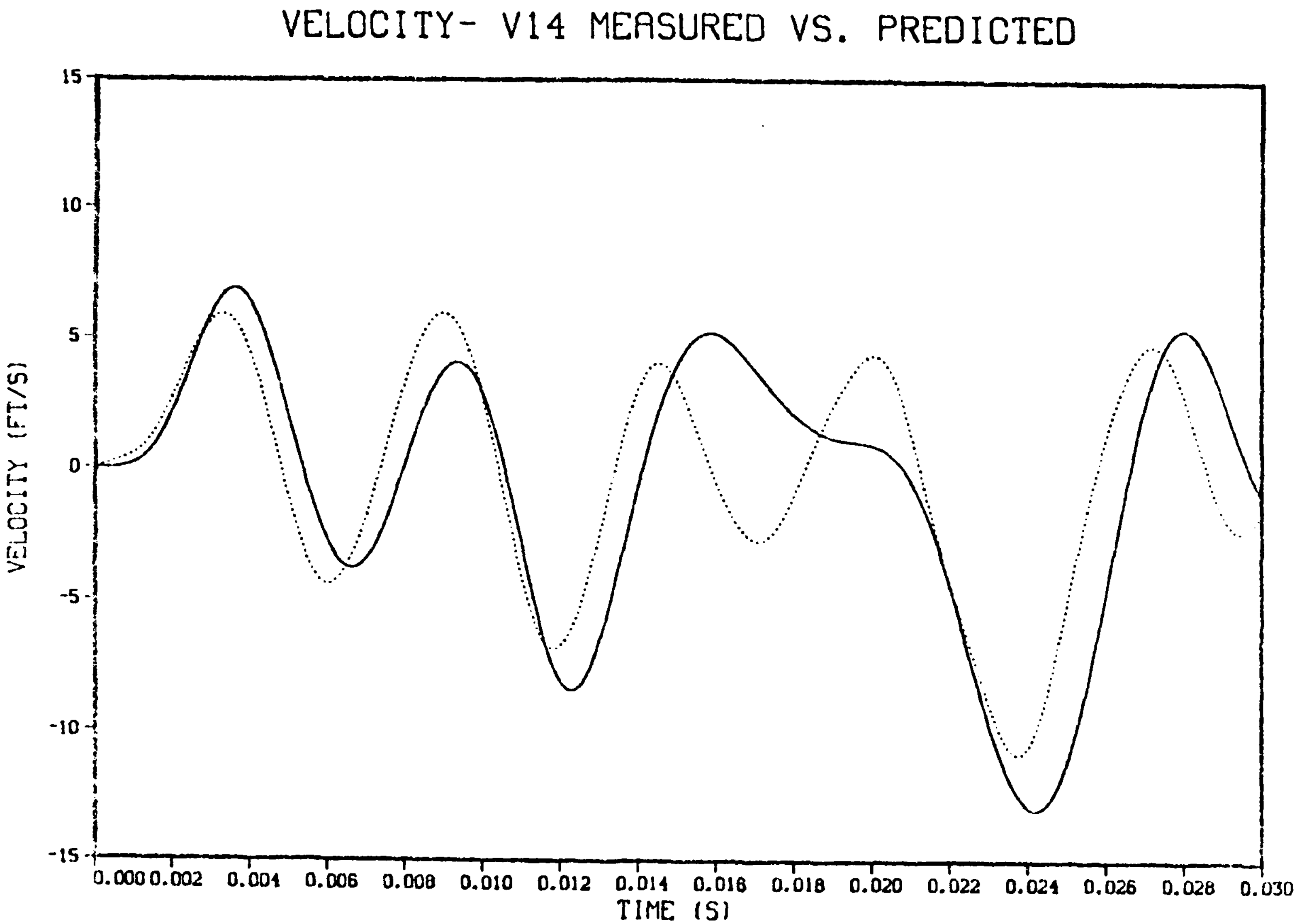

FIGURE 13 - COMPARISON OF VELOCITY MEASURED ON SIMULATED EQUIPMENT BY VELOCITY METER V14 (...) VERSUS PREDICTED (——).

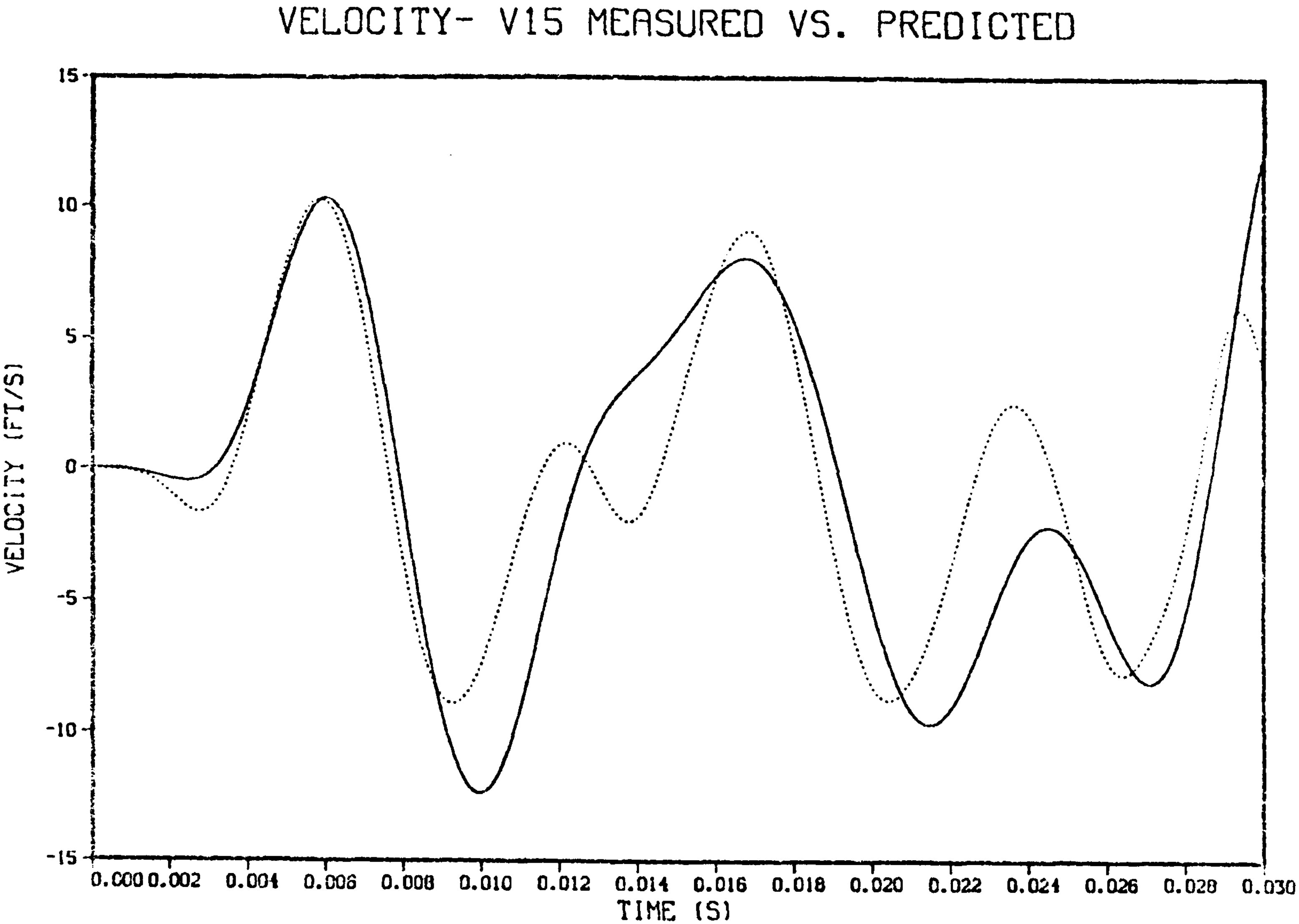

FIGURE 14 - COMPARISON OF VELOCITY MEASURED ON SIMULATED EQUIPMENT BY VELOCITY METER V15 (...) VERSUS PREDICTED (——).

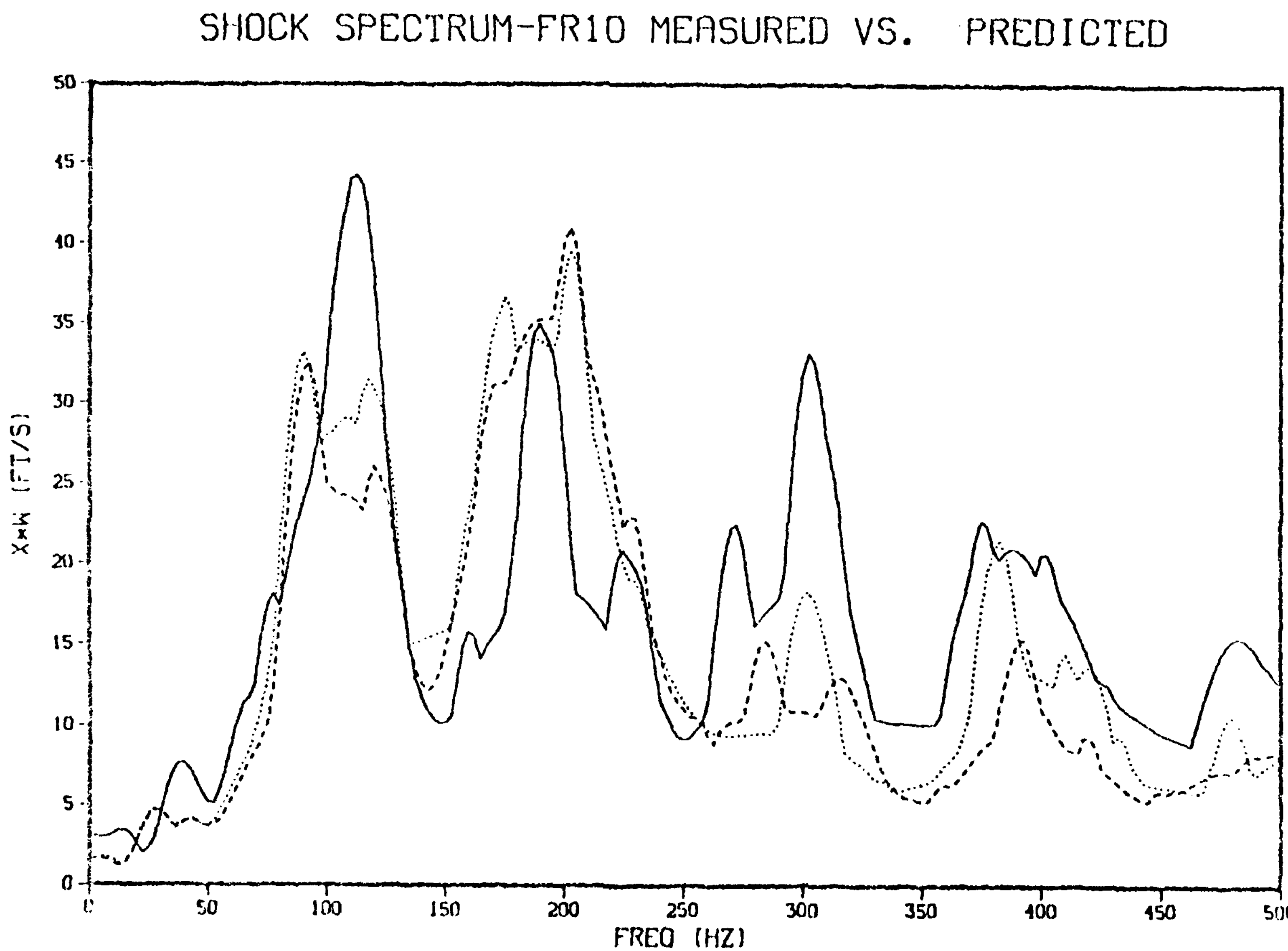

FIGURE 15 - COMPARISON OF SHOCK SPECTRA MEASURED ON FRAME 10 BY VELOCITY METER V5 (...) AND VELOCITY METER V10 (---) VERSUS PREDICTED (——). ELAPSED TIME .05s.

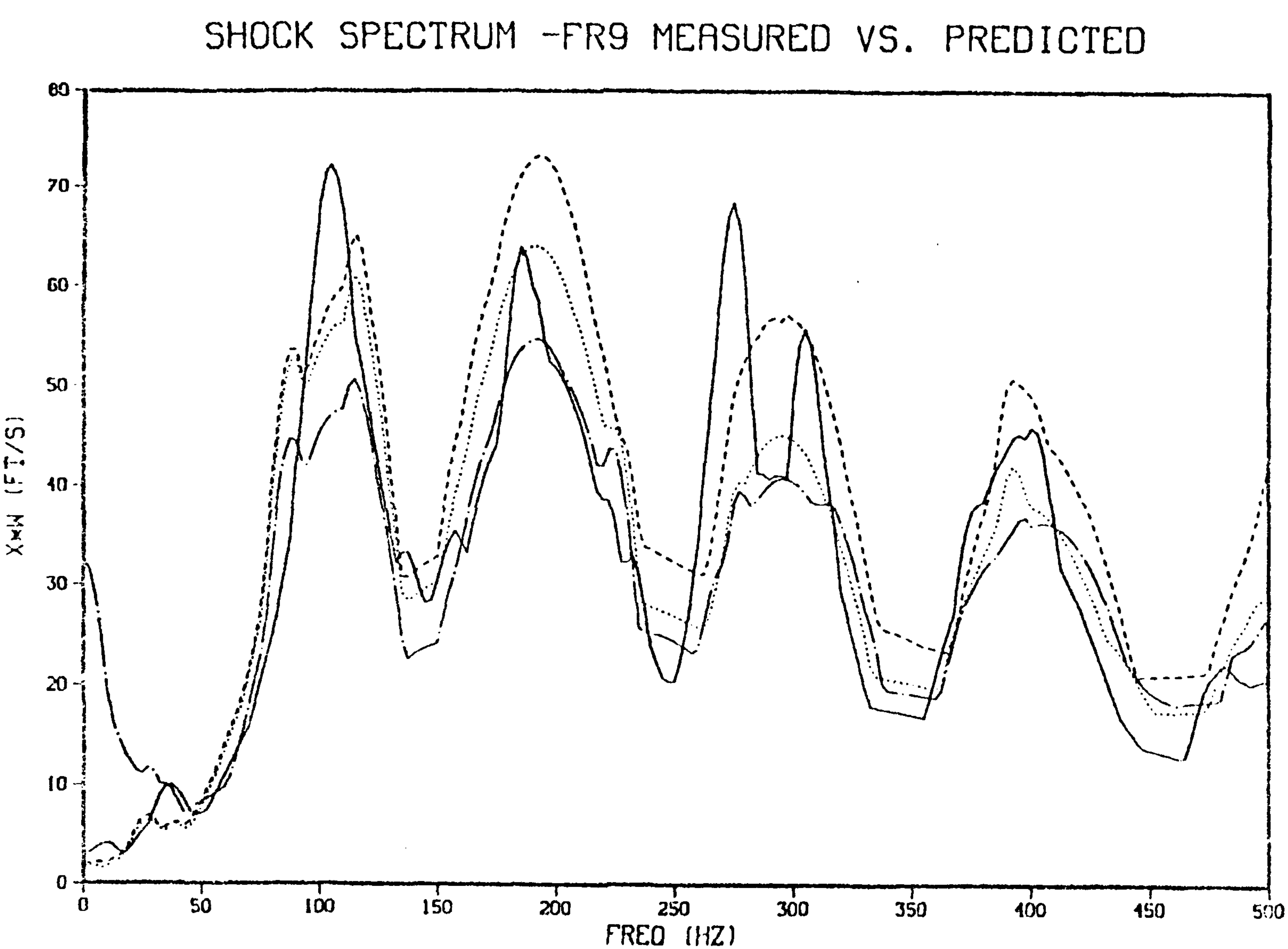

FIGURE 16 - COMPARISON OF SHOCK SPECTRA MEASURED ON FRAME 9 BY VELOCITY METER V6 (...), VELOCITY METER V11 (---) AND ACCELEROMETER A1 (-.-), VERSUS PREDICTED (——). ELAPSED TIME .05s.

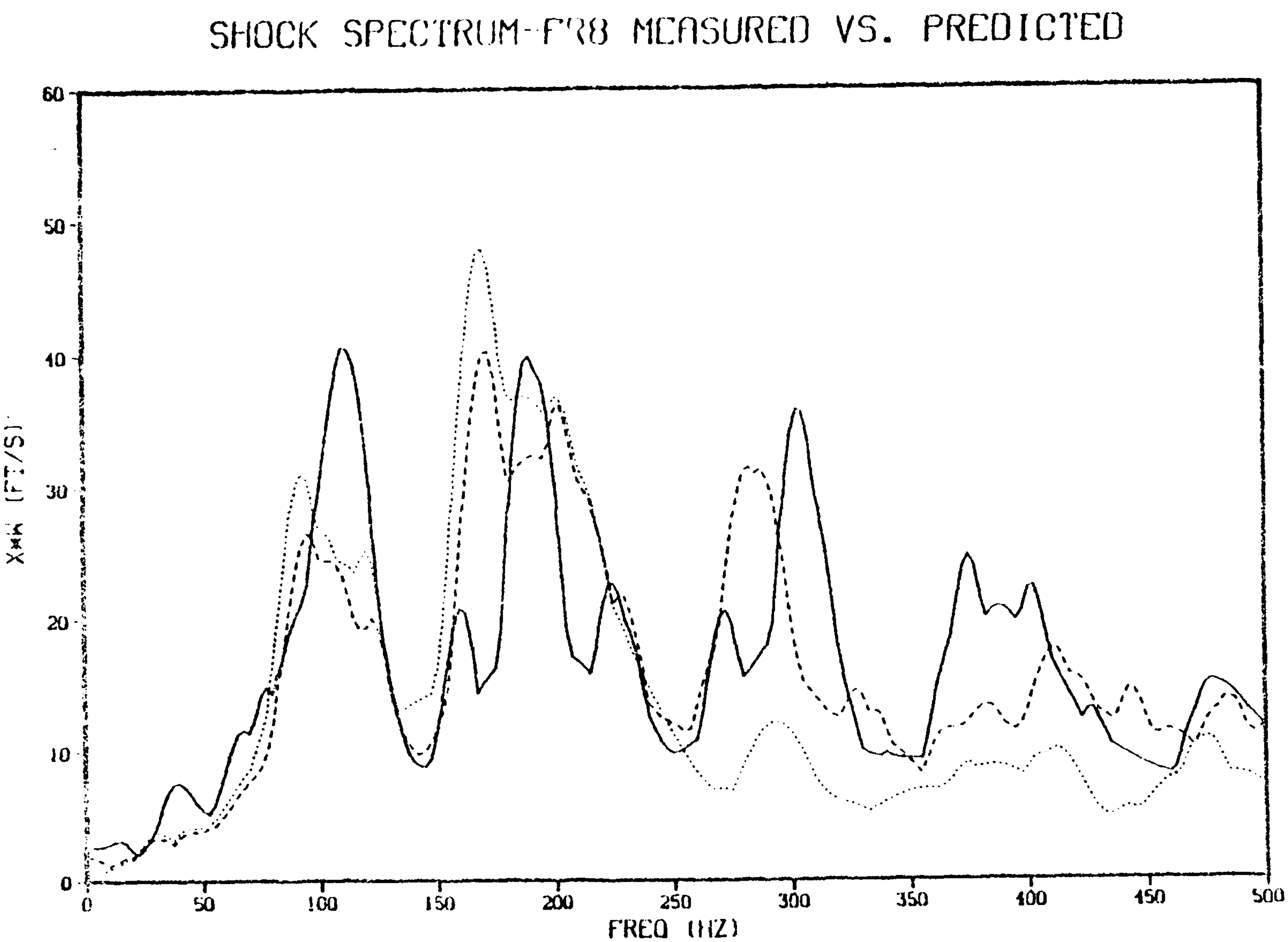

FIGURE 17 - COMPARISON OF SHOCK SPECTRA MEASURED ON FRAME 8 BY VELOCITY METER V8 (...) AND ACCELEROMETER A2 (---), VERSUS PREDICTED (——). ELAPSED TIME .05s.

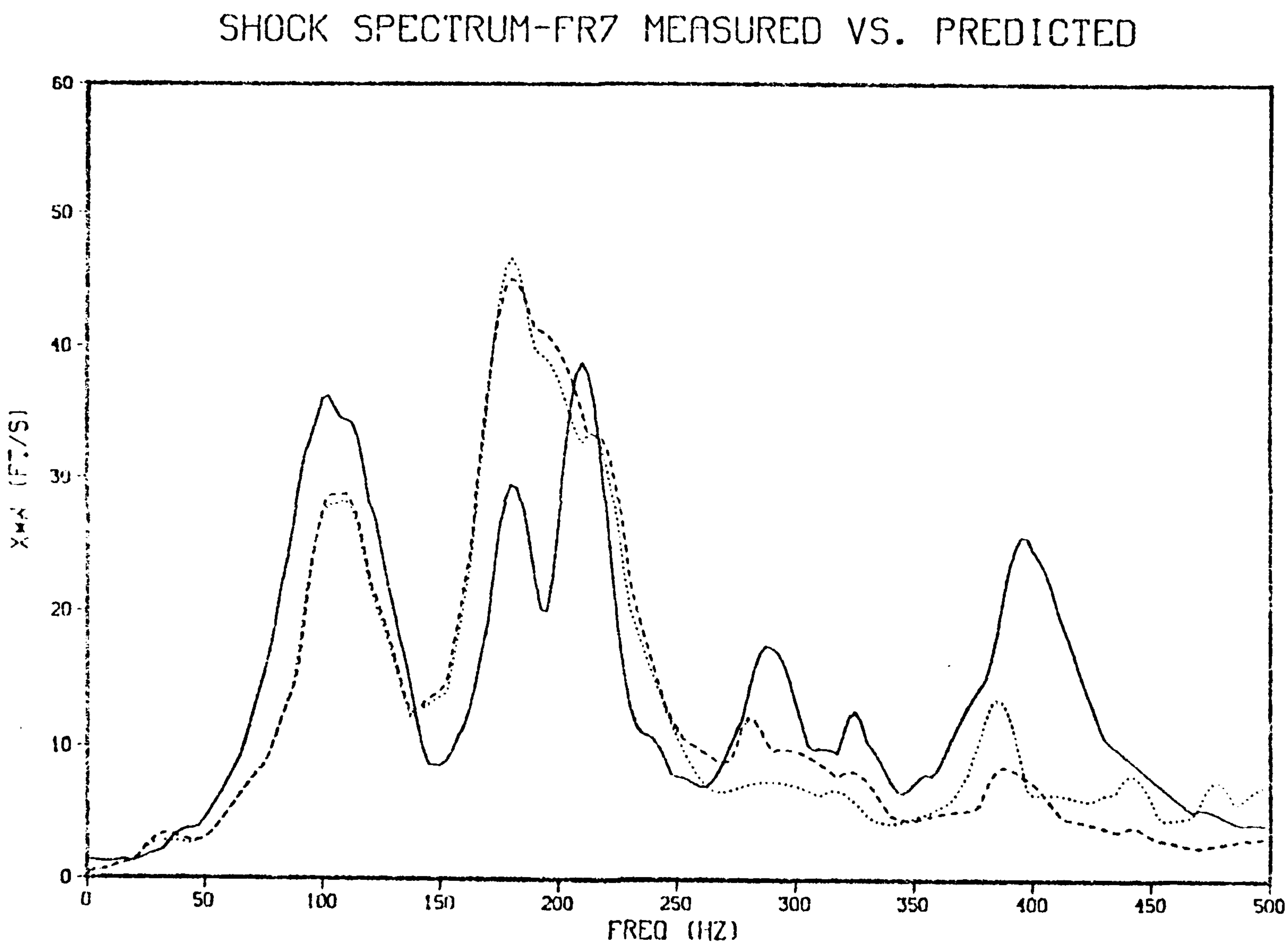

FIGURE 18 - COMPARISON OF SHOCK SPECTRA MEASURED ON FRAME 7 BY VELOCITY METER V9 (...) AND VELOCITY METER V13 (---), VERSUS PREDICTED (——). ELAPSED TIME .05s.

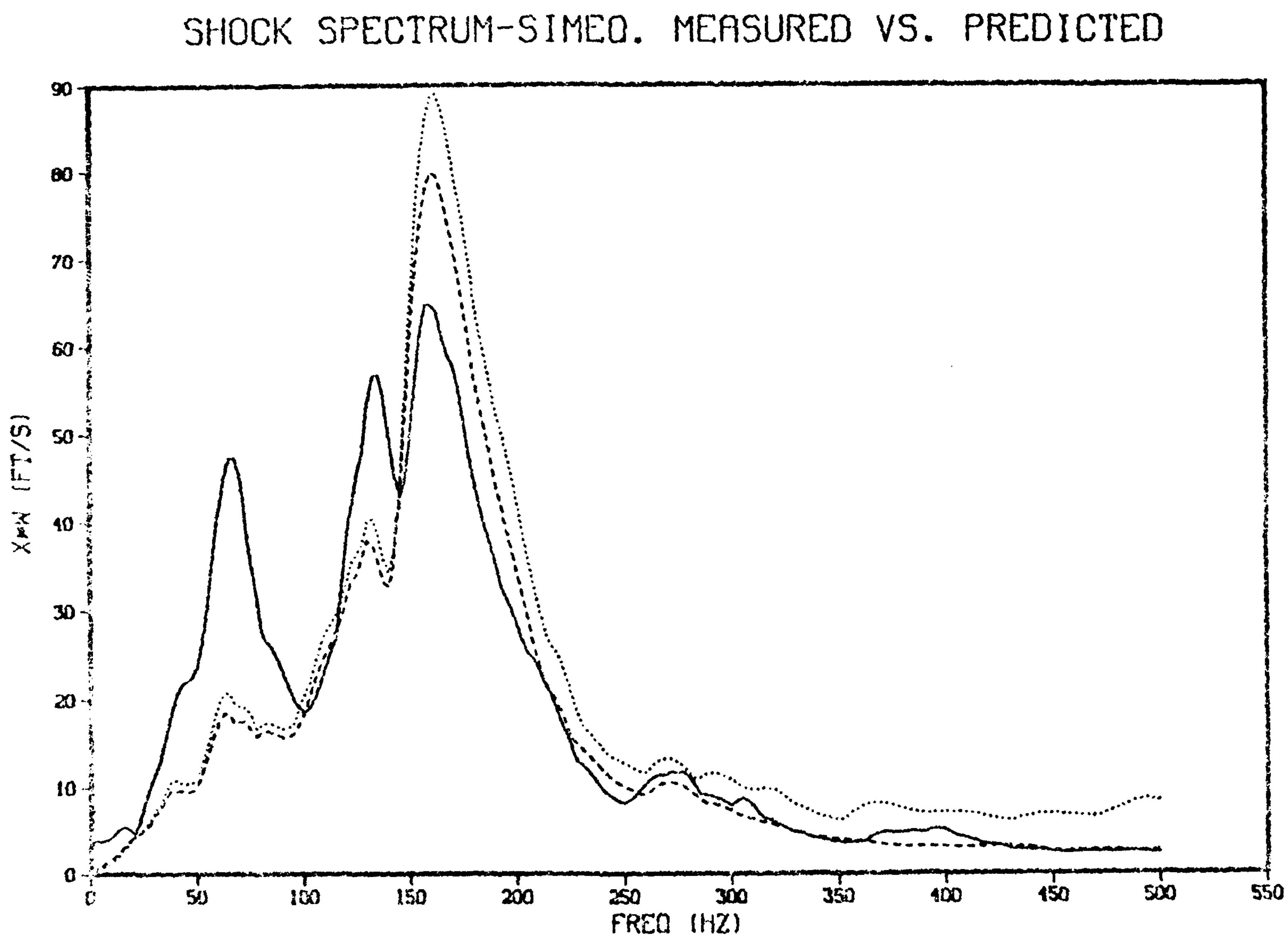

FIGURE 19 - COMPARISON OF SHOCK SPECTRA ON SIMULATED EQUIPMENT MEASURED BY VELOCITY METER V14 (...), AND ACCELEROMETER A3 (---) VERSUS PREDICTED (——). ELAPSED TIME .05s.

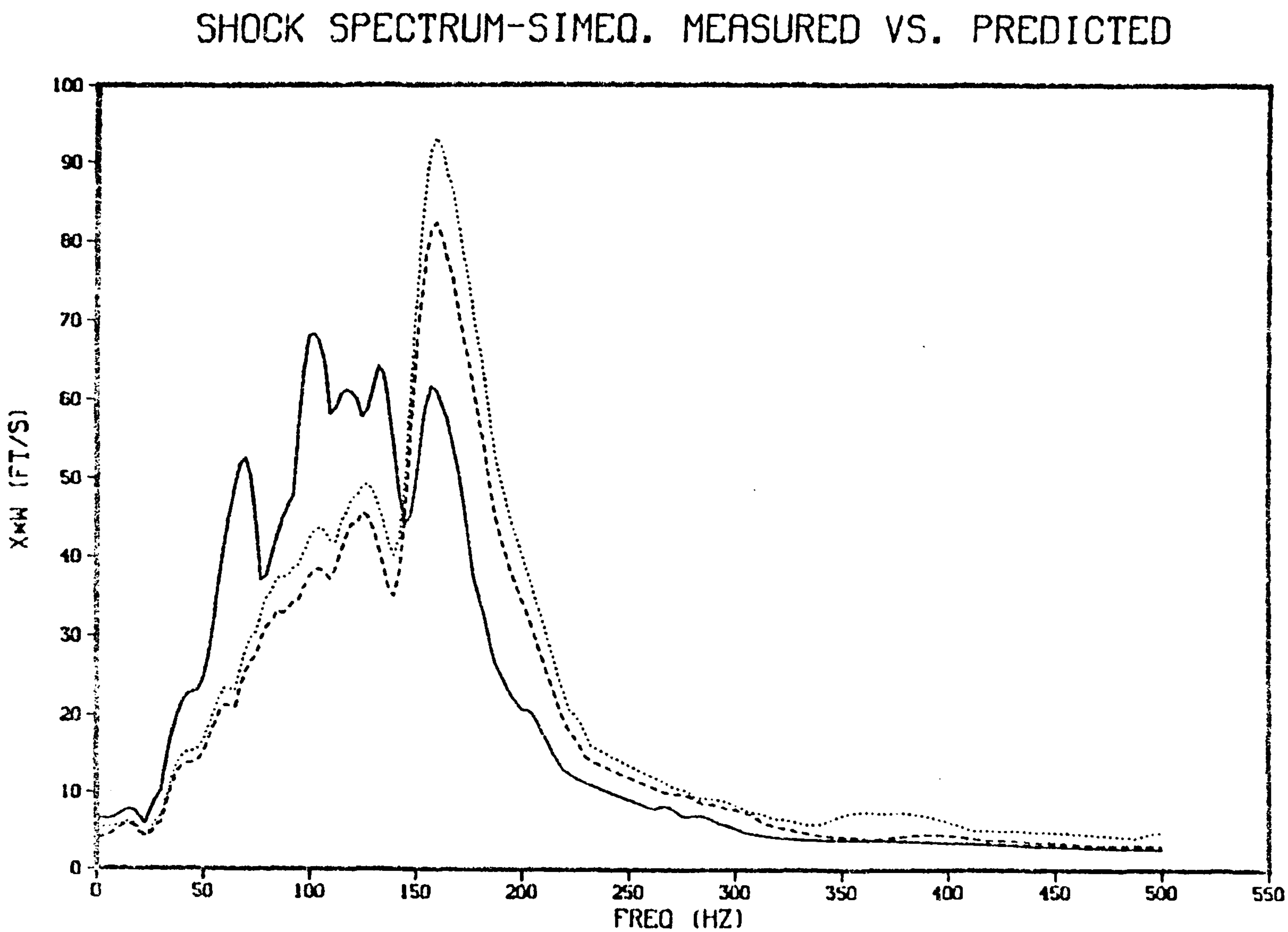

FIGURE 20 - COMPARISON OF SHOCK SPECTRA ON SIMULATED EQUIPMENT MEASURED BY VELOCITY V15 (...), AND ACCELEROMETER A4 (---) VERSUS PREDICTED (——). ELAPSED TIME .05s.

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